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ENVIRONMENTAL SCIENCES DIVISION
Publication No. 1530

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AN INVESTIGATION OF RADIONUCLIDE RELEASE FROM SOLID WASTE DISPOSAL AREA 3, OAK RIDGE NATIONAL LABORATORY

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NUCLEAR WASTE PROGRAMS
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ABSTRACT

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Radionuclide release from Solid Waste Disposal Area (SWDA) 3 has been studied through the analysis of surface and ground waters from the local drainage areas. SWDA 3 is located in the Northwest Tributary drainage basin, a part of the White Oak Creek drainage; ^{90}Sr is the only radionuclide being discharged in solution in the main stream. During seven months of stream monitoring, the ^{90}Sr discharge ranged from 2.1 to 11.1 mCi per month and averaged 6.4 mCi per month. The activity is entering the Northwest Tributary through base flow in a 30-m reach about 350 m from the disposal area. Water-level measurements in wells around SWDA 3 suggest the presence of a ground-water divide beneath the southwestern end of the disposal area. Ground water below this area may be moving southwestward toward the Raccoon Creek drainage system. Strontium-90 activity has been detected in this watershed, discharging from a seep adjacent to a Raccoon Creek tributary stream about 640 m southwest of SWDA 3. The ^{90}Sr discharge is persistent in amounts of about 0.5 mCi per month. The radionuclide could be migrating from the Contractors' Spoil Area, located 250 m southwest of SWDA 3, where two small areas of contaminated fill material were detected.

It appears that ^{90}Sr is moving through ground-water flow to the northeast and to the southwest of SWDA 3 and that this direction of movement is related to bedrock structure. The trend of a line

connecting the two seeps passes through the disposal area and is parallel to bedrock strike. Information from core-hole logs and televiewer logs suggests that ^{90}Sr in ground water may be moving through solution channels near the contact between units F and G of the Chickamauga Limestone. The apparent extent of migration of ^{90}Sr in bedrock has implications regarding potential underground radionuclide movement in Melton Valley.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Shallow-land burial of low-level radioactive waste at Oak Ridge National Laboratory (ORNL) is confined to six solid waste disposal areas (SWDA's). SWDA 3 (Fig. 1), comprised of about 2.8 ha (7 acres), was the third and last site developed in Bethel Valley. It was utilized for burial in the period 1946-1951, when sites were chosen primarily on the bases of security and convenience, without consideration of geologic and hydrologic factors. Relatively little attention has been given to this disposal area because its apparent radionuclide discharge through the Northwest Tributary has been minor when compared with discharges from other sources within the White Oak Creek drainage basin. Limited data based on direct measurements (Lomenick et al. 1962, Stueber et al. 1978) indicate that only small quantities of ^{90}Sr and ^{137}Cs are present in the Northwest Tributary at its confluence with White Oak Creek.

Knowledge of the amounts and types of radioactive contaminants and the details of the waste buried at the site is severely limited, because the burial records were accidentally destroyed by fire in 1961. Stockdale (1951), who studied the geology of the area while the site was operational, described the trenches as being less than 4.6m (15 ft) deep. The orientation of the trenches and the general locations of alpha and beta-gamma wastes in SWDA 3 are shown in Fig. 2, which is based on recollection of the burial operation. After disposal was terminated, the site was used as a secure area for the temporary storage of large pieces of contaminated equipment that might have further use.

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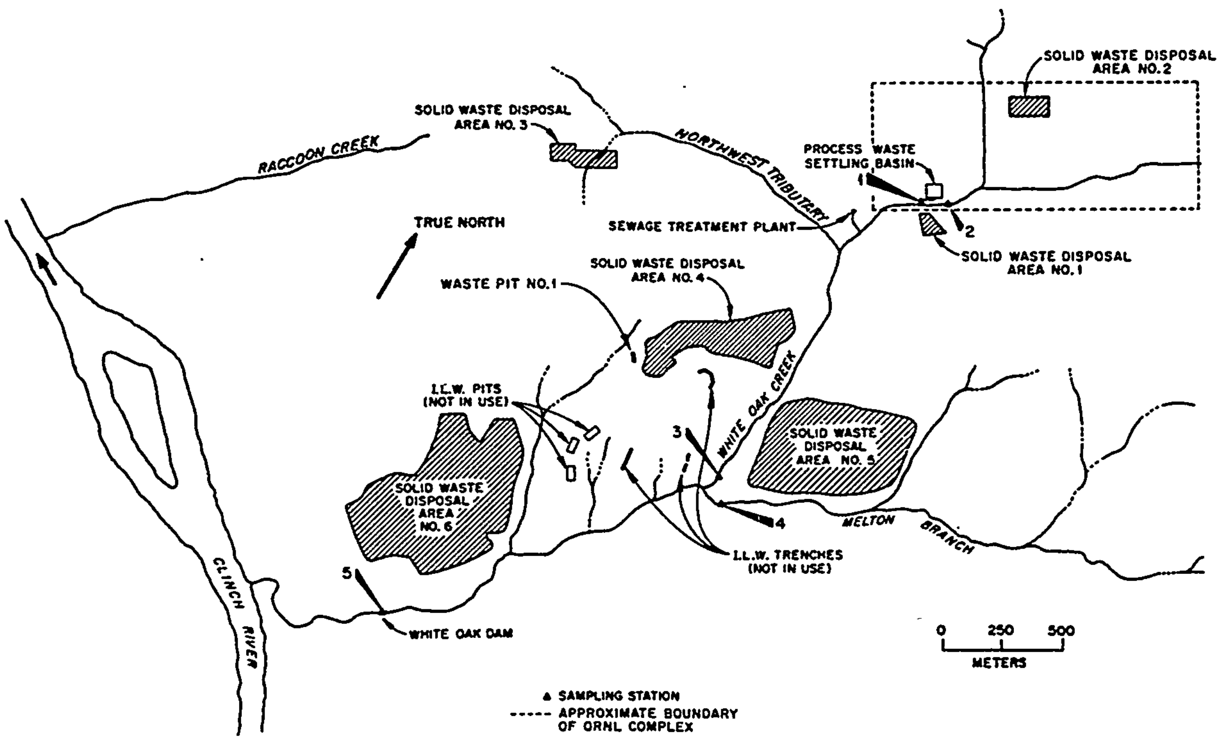

Fig. 1 Drainage systems and locations of waste disposal areas in the ORNL area.

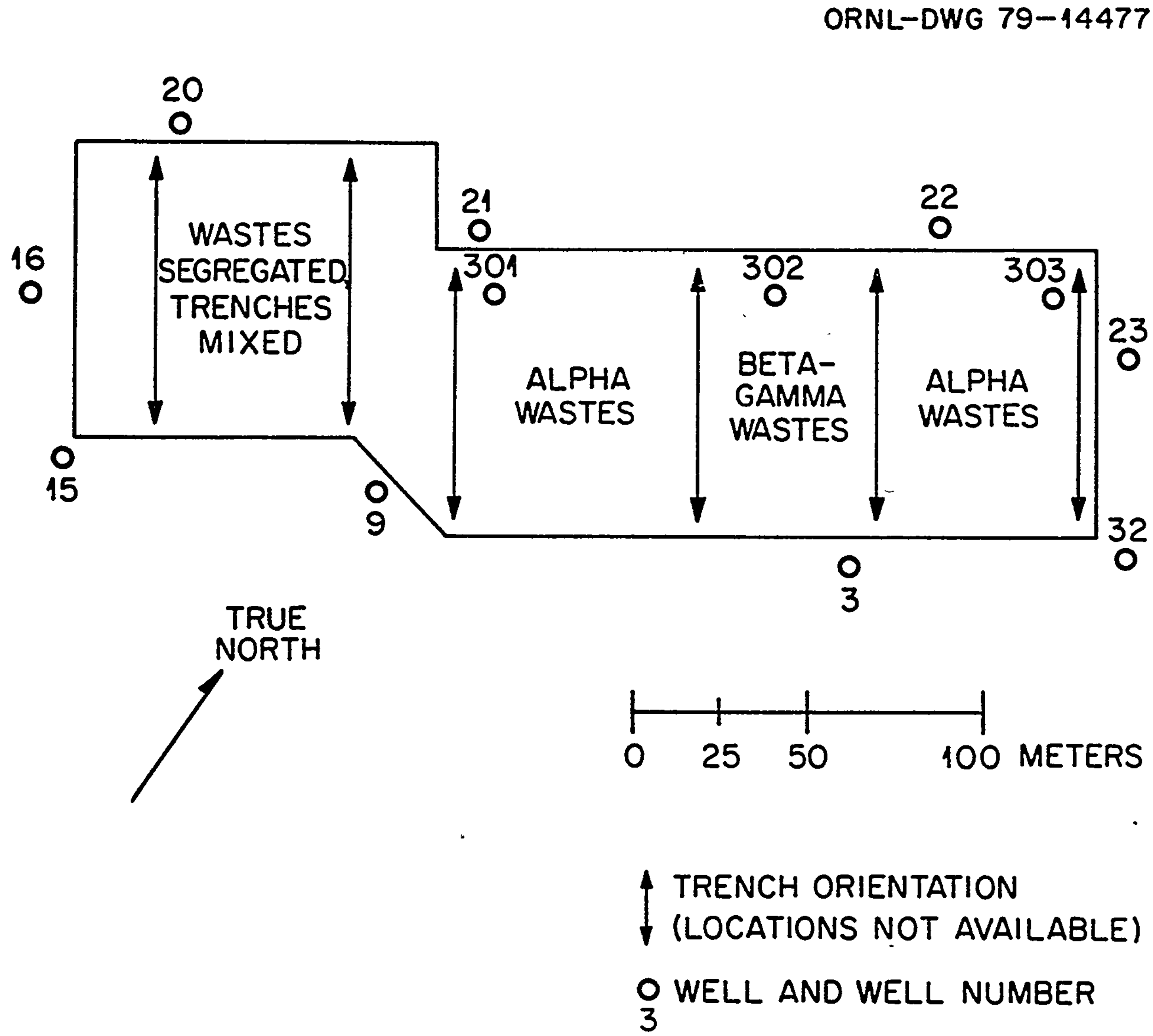

Fig. 2 Schematic diagram showing the orientation and general location of radioactive waste trenches in SWDA 3 (from Webster 1976).

Such equipment was placed on the ground surface where precipitation could mobilize the radioactive contaminants. The equipment has been removed and disposed of elsewhere; the ground surface has been renovated by adding a layer of soil and planting grass.

Geologic and hydrologic factors in the area favor a complex pattern of radionuclide movement from the site. The bedrock underlying Bethel Valley is the Chickamauga Limestone of Ordovician age. This formation is composed predominantly of limestone, although shale, siltstone, and bedded chert represent significant minor components. The strata generally are thin- to medium-bedded. Fractures and solution openings within and between the beds of the Chickamauga represent potential pathways for ground-water movement and radionuclide migration through bedrock in the vicinity of SWDA 3.

A contour map based on water-level measurements in wells on June 20, 1950, indicated the presence of a ground-water divide beneath SWDA 3. Thus it was inferred that ground water east of the divide flows easterly to points of discharge in the White Oak Creek drainage system (Fig. 1), whereas ground water west of the divide flows westerly to points of discharge in the Raccoon Creek drainage system (DeBuchananne, in Stockdale 1951).

The drainage basin divide is not readily defined but appears to occur just west of the disposal site. Therefore, all surface water from SWDA 3 drains to White Oak Creek through the Northwest Tributary.

The purpose of this investigation, conducted from June 1978 through May 1979, was to determine the magnitude and pattern of radionuclide discharge from SWDA 3 by surface and ground waters.

Although SWDA 3 is not suspected of being a major source of radionuclide release to the White Oak Creek drainage system at the present time, its relative importance as a source of ^{90}Sr has risen and will continue to rise in the future as corrective measures to reduce direct discharges to White Oak Creek are implemented elsewhere. In addition, this study was warranted because of the potential for deeper radionuclide circulation in the bedrock, the possible movement of ground water and radionuclides to the unmonitored Raccoon Creek drainage system, and the need to evaluate radionuclide release from the contaminated equipment stored on the surface of SWDA 3.

RADIONUCLIDE DISCHARGE THROUGH THE NORTHWEST TRIBUTARY TO WHITE OAK CREEK

The Northwest Tributary (NWT) originates on the northwest flank of Haw Ridge; runoff from this area, which formerly passed through SWDA 3, is diverted around the northeastern end of the disposal area (Figs. 1 and 3). The stream is ephemeral in the vicinity of the disposal area; it becomes perennial about 400 m downstream from the site. The radionuclide content of the stream may be acquired by transport in ground water from the waste buried in SWDA 3 and by leaching of the contaminated equipment on the ground surface.

The ^{90}Sr discharge of the Northwest Tributary was monitored at a point 60 m above its confluence with White Oak Creek (Fig. 3). Staff gage readings and water samples were taken on a daily basis for seven nonconsecutive one-month periods. Streamflow values were obtained from stage-discharge rating curves that had been previously established (Laib and Huff 1978). By inspection of the stream hydrograph, the

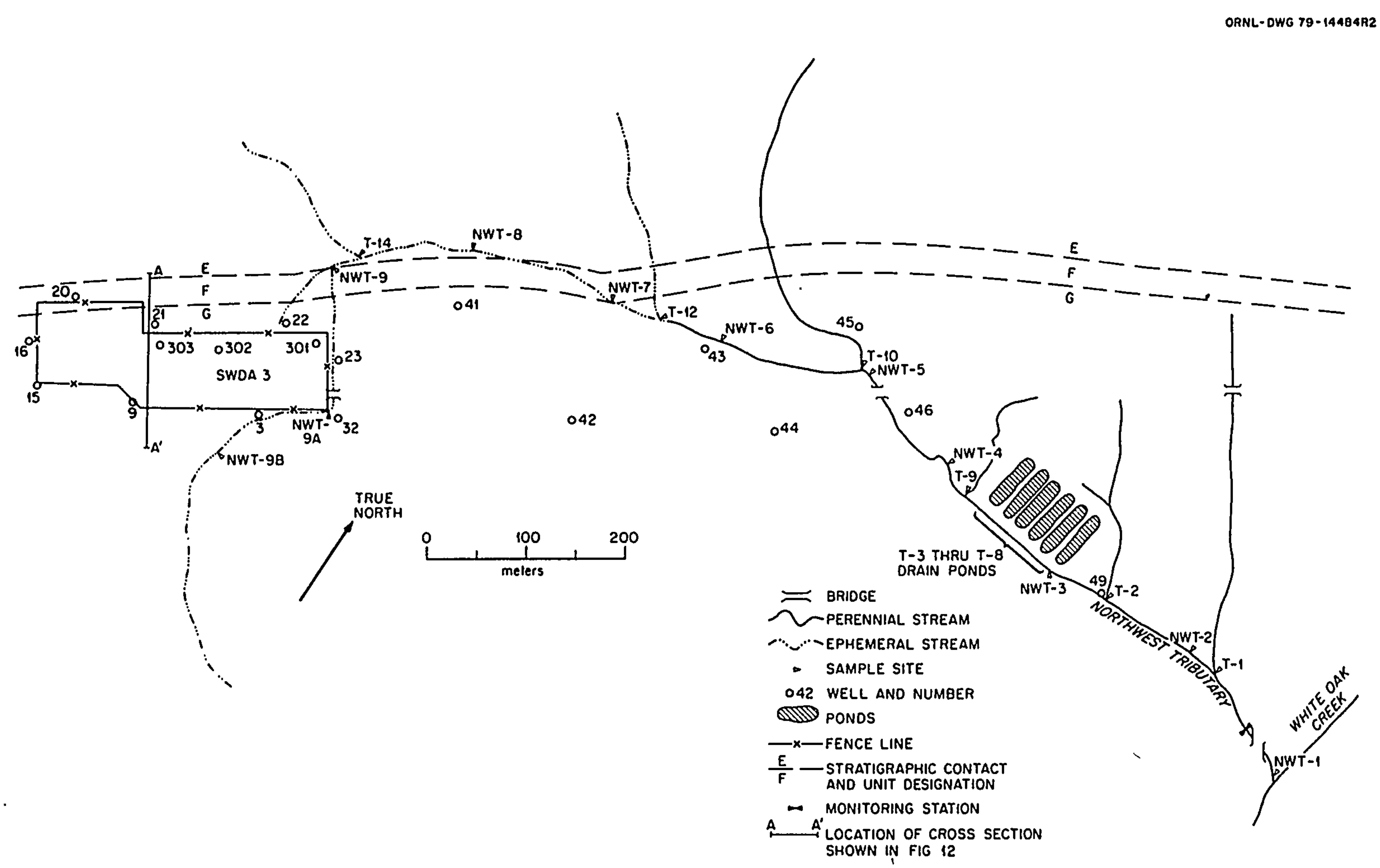

Fig. 3 The Northwest Tributary drainage basin, including surface-water sampling sites, wells, and contacts of Chickamauga Limestone bedrock units.

month was divided into four to five periods of approximately equal daily discharge. Composite water samples, containing equivalent volumes from each daily sample, were prepared for each period represented. The composite samples were analyzed for ^{90}Sr; the activity in each sample was multiplied by the integrated streamflow to yield the ^{90}Sr discharge for that time interval. These increments were summed to provide monthly ^{90}Sr discharge values for the Northwest Tributary during the period of this investigation. The monthly discharge values are given in Table 1.

The amount of ^{90}Sr discharged by the Northwest Tributary ranged from 2.1 to 11.1 mCi per month and averaged 6.4 mCi per month for the seven months of monitoring. The data of Lomenick et al. (1962) for a five-month period in 1961 yielded a mean value of 6.6 mCi per month. While the ^{90}Sr discharged by the Northwest Tributary generally increased with increasing precipitation during the period of this investigation (Table 1), the relative importance of this source as a contributor of ^{90}Sr to White Oak Creek between monitoring stations 2 and 3 declined. This relationship is due to the much greater discharge of ^{90}Sr from SWDA 4 than from SWDA 3 following periods of prolonged or intense precipitation.

In order to locate the sources of ^{90}Sr input to the Northwest Tributary, water samples were collected from this stream at 150-m intervals from its confluence with White Oak Creek to its origin above SWDA 3 (Fig. 3). All tributaries were also sampled just above their points of confluence with the stream. The first suite of samples was obtained on June 6, 1978, following an extended period devoid of

Table 1. Monthly ^{90}Sr discharge of the Northwest Tributary and the percent contribution to the net ^{90}Sr discharge of White Oak Creek between monitoring stations 2 and 3

Month	^{90}Sr discharge (mCi)	Precipitation (cm)	Percent contribution
9-78	3.2	3.5	18.8
10-78	2.1	2.9	21.9
11-78	4.0	13.3	5.3
12-78	10.5	17.6	6.6
1-79	11.1	17.9	3.3
4-79	5.7	13.8	3.4
5-79	8.2	25.8	5.8

precipitation. The Northwest Tributary had no flow upstream from a point near its confluence with tributary T-12 (between sampling sites NWT-6 and NWT-7); water samples upstream from this location were collected from pools of standing water in the stream channel. Each sample was filtered through Whatman filter paper No. 42, acidified with HNO_3 to pH 1-2, and analyzed for ^{90}Sr and gamma activity. The ^{90}Sr analytical data are tabulated in Appendix A; the gamma activity was below detection limits in all but two water samples, which showed negligible concentrations (<0.2 pCi/ml) of ^{137}Cs.

A longitudinal profile of ^{90}Sr activity in the Northwest Tributary on June 6, 1978, is shown in Fig. 4. A ^{90}Sr concentration of 2.9 pCi/ml was measured at site NWT-6 (Fig. 3), where the stream was being maintained by base flow. Downstream from this point the ^{90}Sr activity was reduced by more than an order of magnitude due to dilution by tributary waters. Upstream from site NWT-6 the ^{90}Sr concentrations in the pools of standing water were near background level (<0.01 pCi/ml). Thus it appears that on June 6 the ^{90}Sr in the Northwest Tributary was being introduced by ground-water discharge between sampling sites NWT-6 and NWT-7.

A second suite of water samples was collected from the Northwest Tributary on June 9, 1978, after a period of intense rainfall. The stream was flowing over its entire length. The profile of ^{90}Sr activity in the stream (Fig. 4) again showed a maximum at site NWT-6, but the concentration (0.12 pCi/ml) was more than an order of magnitude lower than the value found on June 6. Apparently the input of ^{90}Sr through base flow near this site was diluted considerably by the high

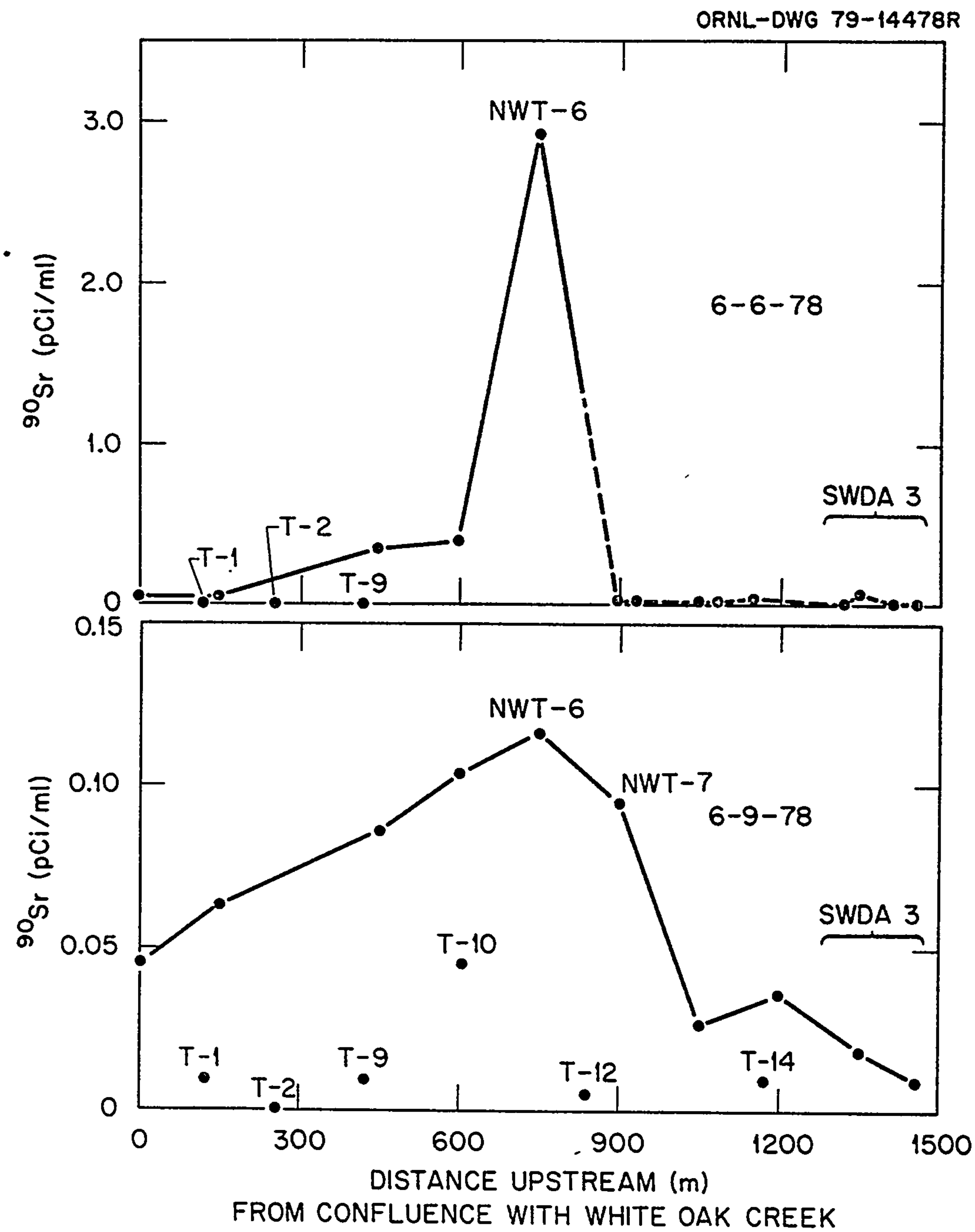

Fig. 4 Longitudinal activity profiles of ^{90}Sr in the Northwest Tributary for June 1978. Dashed line indicates stream interval having no flow on June 6, 1978.

streamflow on this date. The activity profile also indicated that ^{90}Sr was being introduced in the vicinity of site NWT-7, although this was not evident from the data of June 6 (Fig. 4).

Because of the high surface runoff on June 9, the activity profile for that date should give a good indication of the ^{90}Sr contribution to the Northwest Tributary from the contaminated equipment on the surface of SWDA 3. Stream samples collected adjacent to the disposal area (Fig. 4) show that the apparent ^{90}Sr input from this source was minor, amounting to 0.04 pCi/ml or less per sample.

In order to define more precisely the Northwest Tributary reach where ^{90}Sr is being introduced through base flow, two suites of stream samples which involved more intensive sampling over the reach of interest were obtained during January 1979. In addition to collecting water samples at the regular locations, samples were also collected at 30-m intervals between sites NWT-5 and NWT-8 (Fig. 3). The longitudinal profile of ^{90}Sr activity in the stream on January 5, when the flow at the monitoring station was 0.052 m^3/s, is shown in Fig. 5. There was an abrupt increase in activity in a downstream direction from essentially background level to 0.35 pCi/ml within a 30-m interval located between 810 and 840 m upstream from the confluence with White Oak Creek. The activity profile on January 18 (Fig. 5), when the streamflow was 0.033 m^3/s, showed the same pattern with a sharp rise in ^{90}Sr concentration from background to 1.08 pCi/ml in the same 30-m stream interval. On both occasions, the elevated ^{90}Sr activity levels persisted over 180 m in a downstream direction; the ^{90}Sr concentration in the Northwest Tributary then declined sharply due to the dilutive effect of tributary T-10.

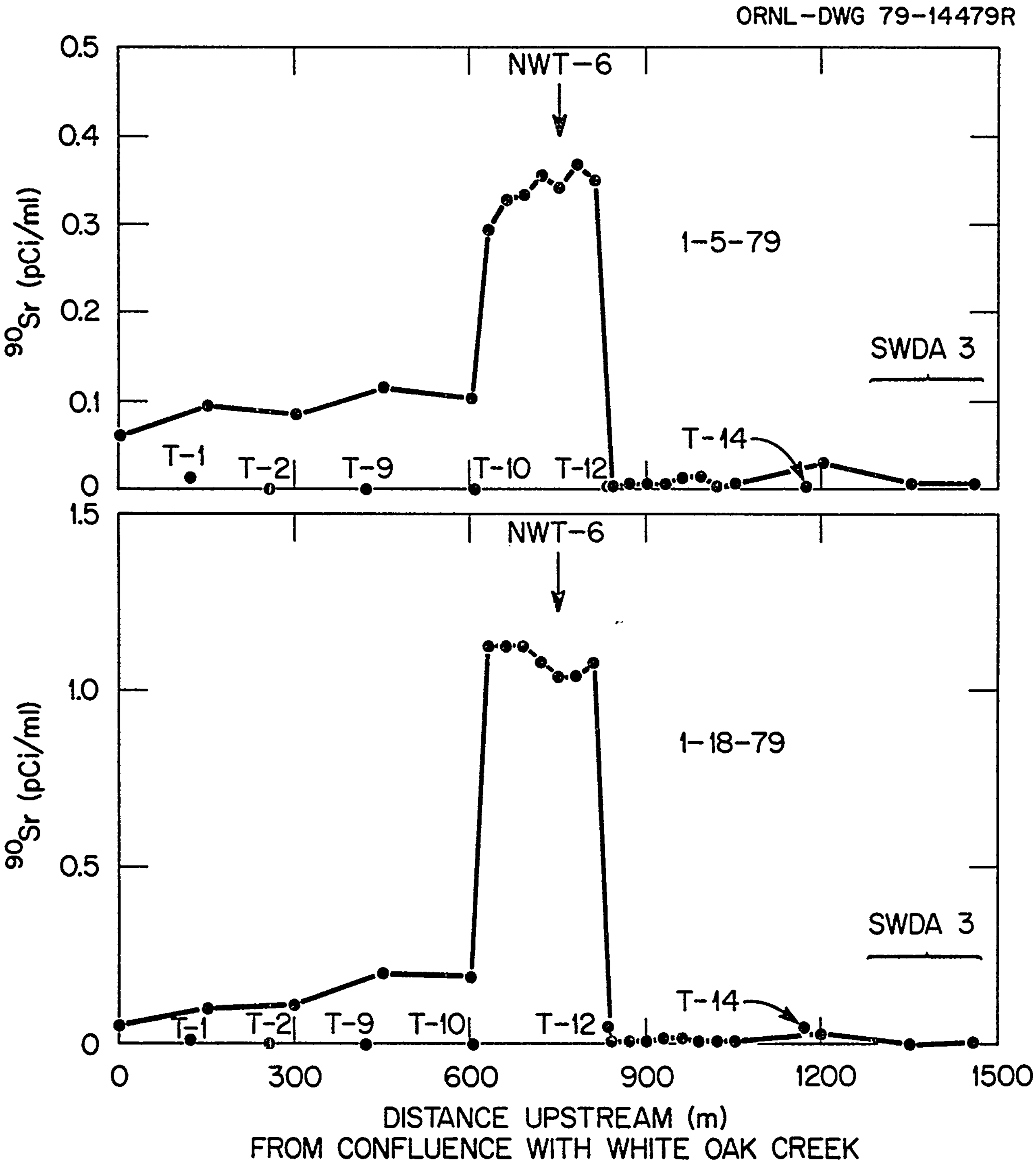

Fig. 5 Longitudinal activity profiles of ^{90}Sr in the Northwest Tributary for January 1979.

Within the precision of the ^{90}Sr analyses, which is approximately $\pm 5\%$, the ^{90}Sr activity showed only a small degree of variability in the Northwest Tributary reach between 630 and 810 m upstream from the confluence with White Oak Creek. The profile for January 5 (Fig. 5) suggests a slight decrease in ^{90}Sr activity in a downstream direction within this reach; although no tributaries enter the stream, this effect could be due to dilution by base flow. On the other hand, activity variations in this stream interval, if real, could reflect incomplete mixing between ground water from the ^{90}Sr source and surface water from tributary T-12 (Figs. 3 and 5). Although the situation may be more complex, the ^{90}Sr activity profiles strongly suggest that nearly all the ^{90}Sr discharged to White Oak Creek by the Northwest Tributary is being introduced into the stream by ground-water flow within a 30-m interval located about 350 m from the northeast boundary of SWDA 3.

SUBSURFACE HYDROLOGIC CONDITIONS IN THE VICINITY OF SWDA 3

Information regarding subsurface hydrologic conditions in the vicinity of SWDA 3 was obtained from 16 deep wells (Fig. 3 and Table 2) which were drilled in late 1949 and early 1950 as part of a program designed to study the geology and hydrology of Bethel Valley (Stockdale 1951). Three additional shallow wells were subsequently installed inside the disposal area (Gera 1964). Ground water occurs both in the residuum or weathered zone and in the Chickamauga Limestone bedrock. Below the weathered zone, the circulation of water is limited by the occurrence of secondary openings. After a study of drill cores,

Table 2. Information regarding wells in the vicinity of SWDA 3. All measurements in feet[a] below land surface.

Well	Bedrock units penetrated	Overburden thickness	Well depth	Depth to water 7-12-78	Depth to water 1-26-79
3	G,F	12.0	250.7	8.70	5.87
9	G	22.0	98.7	20.47	18.04
15	G	25.0	99.6	28.04	22.19
16	G,F,E	12.0	99.9	28.75	26.02
20	F,E	12.5	99.0	21.01	20.63
21	G,F,E	12.0	99.8	25.50	24.49
22	G,F,E	10.5	100.5	14.78	10.45
23	G	10.0	100.0	5.25	1.01
32	G	8.7	99.3	10.31	6.44
41	G,F	10.0	33.5	32.22	32.22
42	G	1.0	49.2	19.65	11.95
43	G	9.5	46.5	5.62	4.69
44	G	9.0	49.4	19.05	18.58
45	G	6.5	24.2	3.05	0.98
46	G	3.0	50.3	2.99	1.63
49	H	8.0	46.6	2.43	1.15
301	-	-	14.1	6.37	2.18
302	-	-	6.3	3.53	2.62
303	-	-	6.2	3.23	1.43

[a]1 ft = 0.3048 m.

Stockdale reported the presence of relatively small solution openings in the bedrock unit that underlies SWDA 3.

Logs of the core holes suggest that the residuum-bedrock contact is an irregularly shaped surface with highs in the vicinity of wells 16 and 32 (Fig. 3). A low occurs near wells 22 and 23. Frequent measurements of water levels in the nine wells immediately surrounding SWDA 3 suggest that the water surface reflecting the contact between the zone of aeration and the zone of saturation occurs in the residuum perenially over most of the disposal area southeast of a line from well 23 to well 9. To the northwest of a line from well 22 to well 16, the contact occurs perennially in bedrock. In the vicinity of well 15, the water surface fluctuates between bedrock and residuum during the year. Thus, ground water and dissolved radionuclides in the saturated zone move through both the residuum and bedrock in the southeastern half of the disposal site, but only through the bedrock in the northwestern half.

The water-level data also indicate that, if the trenches are 4.6 m (15 ft) deep (Stockdale 1951), waste in the bottom portions of trenches in the northeast quarter of the disposal area is perennially saturated. The elevations of the water surface in shallow wells 301, 302, and 303, located within SWDA 3 (Fig. 3), tend to be somewhat higher than would be indicated by contours of the water surface based on water levels in the surrounding wells. This suggests that the water in the shallow wells may be perched, possibly due to the low permeability of the clay soil. It is also possible that these wells, installed more than a decade after site closure, may terminate in trenches.

In order to study the migration of radionuclides from the buried waste in SWDA 3, on July 10, 1978, water samples were collected from the 19 wells located in the area (Fig. 3). Duguid (1975) reported ^{90}Sr analyses for water samples obtained November 13, 1973, from the 12 wells that are within and immediately around the disposal area (Table 3). Our water samples were analyzed for gross alpha and gamma activities in addition to ^{90}Sr. The ^{90}Sr data are presented in Table 3; alpha activity was not detected in any of the samples, and minor gamma activity was found only in water from wells 3 and 9 (Table 3, footnote). The latter samples may reflect contamination from the equipment stored on the surface of SWDA 3.

During January 1979, when the major portion of the surface-water sampling program was carried out, the group of wells was sampled five times and composite samples were prepared of water from each well. The ^{90}Sr concentrations of each composite sample (Table 3) should be more representative of activity levels over an extended period of time. In general the activities found during January 1979 were lower than those of July 10, 1978; this may be due to dilution by recharge during the wet season, as suggested by the water levels in the wells (Table 2).

A water-level contour map (Fig. 6), based on water-level measurements in wells on January 26, 1979 (Table 2), shows essentially the same features as a similar map presented by DeBuchananne (in Stockdale 1951) for June 1950. Such maps can be used to predict the direction of ground-water flow, based on the premise that in an unconfined, isotropic aquifer system ground water will flow down-gradient in a direction normal to the water-level contours. In

Table 3. Strontium-90 concentrations (pCi/ml) in ground-water samples from wells in the vicinity of SWDA 3. For well locations see Fig. 6.

Well	11-13-73[a]	7-10-78	1-79
3	≤0.05	0.14[b]	0.01
9	1.49	0.05[c]	0.01
15	≤0.05	1.08	0.63
16	0.50	0.21	0.14
20	≤0.05	<0.01	<0.01
21	0.27	0.05	0.06
22	≤0.05	<0.01	0.05
23	≤0.09	<0.01	<0.01
32	≤0.05	<0.01	0.01
41	-	1.98	0.77
42	-	<0.01	0.01
43	-	0.02	0.05
44	-	<0.01	<0.01
45	-	<0.01	<0.01
46	-	<0.01	0.02
49	-	0.01	0.01
301	0.14	0.07	<0.01
302	0.45	0.42	0.16
303	0.27	0.18	0.13

[a]Duguid 1975.

[b]Concentration of ^{137}Cs = 0.18 pCi/ml; ^{60}Co = 0.05 pCi/ml.

[c]Concentration of ^{137}Cs = 0.08 pCi/ml.

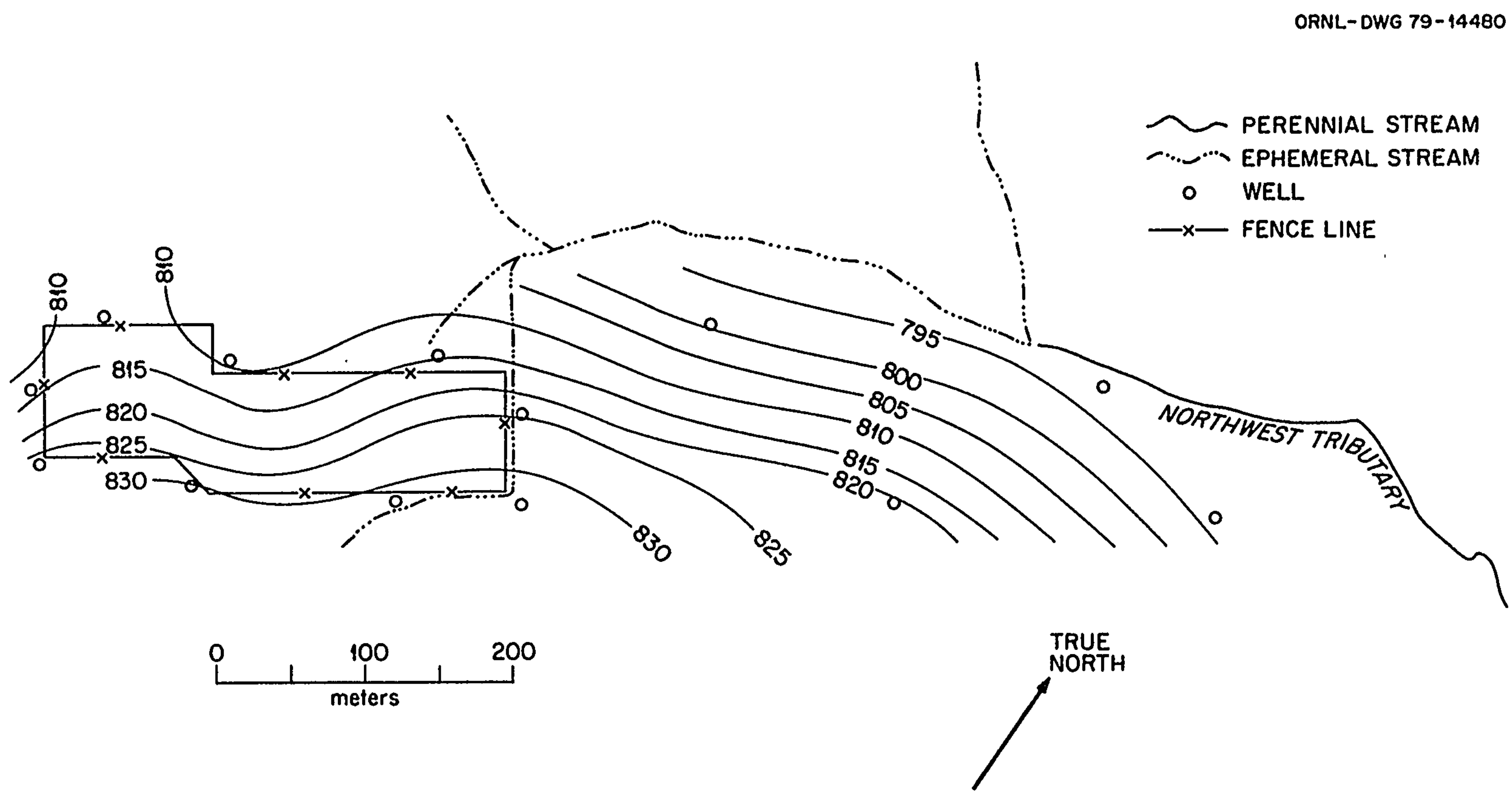

Fig. 6 Water-level contour map based on water levels in wells around SWDA 3 on January 26, 1979.

the vicinity of SWDA 3, these predictions may be valid only for water in the weathered zone because the direction of its movement in bedrock is dependent primarily on the three-dimensional geometry of secondary openings in the rock and the extent of interconnection with other openings of lower hydraulic head. In effect, the bedrock is anisotropic.

The water-level contour map (Fig. 6) suggests that the direction of ground-water flow below the northeastern portion of SWDA 3 is toward the northwest, and beyond the northeastern boundary of the site the flow appears to be generally to the north. Below the southwestern portion of SWDA 3 the hydraulic gradient slopes in two directions; hence, the inferred direction of flow is toward the northeast and toward the west. The contour map cannot be extended west of SWDA 3 because wells have not been installed in that area. However, in view of the general similarity between water-level contours and topographic contours elsewhere in the White Oak Creek drainage basin, it is reasonable to assume that a water-level contour map of this area would suggest ground-water flow to the southwest toward the headwaters of Raccoon Creek.

Water samples from wells 15 and 16 on the southwest perimeter of the disposal area have comparatively high ^{90}Sr concentrations (Table 3), suggesting that this radionuclide may be migrating toward the Raccoon Creek drainage system (Fig. 1). Lower ^{90}Sr activities were measured in water samples from wells 21 and 22 on the northwest perimeter of SWDA 3. Activity profiles of ^{90}Sr in the Northwest Tributary (Figs. 4 and 5) indicate that the concentration of this radionuclide being introduced directly into the stream through the northwestward migration of ground water from the disposal area, as inferred from the water-level contours, is very small (Tables A-1 and A-2, sample NWT-9).

The highest ^{90}Sr activities were found in water samples from well 41 (Table 3), located 146 m northeast of SWDA 3. The water-level contours (Fig. 6) suggest that activity at this point is not being transmitted by flow strictly along the inferred path of flow, assuming isotropic, porous-media flow. Movement through solution openings and/or fractures in the bedrock appears to be more likely. The ^{90}Sr concentrations in ground water at this location and the surface-water evidence presented earlier indicate that the radionuclide is migrating well beyond the perimeter of the disposal area. It would appear that movement of ^{90}Sr to the location where it is entering the Northwest Tributary is taking place by ground-water flow in the bedrock, rather than in the weathered zone.

INVESTIGATION OF THE RACCOON CREEK DRAINAGE BASIN

The ground-water divide inferred to underlie SWDA 3 suggests that ground water below part of the southwestern one-third of this disposal area moves westward. Detection of ^{90}Sr activity levels as high as 1.08 pCi/ml in water samples from two wells just outside the southwestern boundary of SWDA 3 implies that this radionuclide may be migrating to the Raccoon Creek watershed. Any ^{90}Sr released through Raccoon Creek would reach the Clinch River without being detected by the ORNL monitoring system (Fig. 1).

Raccoon Creek originates on the northeast side of U. S. Highway 95, where two surface-runoff channels merge (Fig. 7); it flows southwestward over a distance of 2130 m and enters the Clinch River. On January 17, 1979, a suite of 17 water samples was collected from Raccoon Creek at regular intervals; each of five tributaries was sampled at a point just above its confluence with the creek. The ^{90}Sr analyses (Appendix A), plotted as a longitudinal activity profile in Fig. 8, show that the activity in Raccoon Creek water was at background level (< 0.01 pCi/ml) from the creek's origin to a point about 375 m downstream, where a concentration of 0.07 pCi/ml was detected. Further downstream the ^{90}Sr activity gradually decreased, reaching background level again near the Clinch River estuary.

The ^{90}Sr in Raccoon Creek is being introduced through tributary T-1 (Figs. 7 and 8), which had a concentration of 0.09 pCi/ml when the suite of samples was collected. On March 1, 1979, water samples were collected from this tributary stream at regular intervals from its confluence with Raccoon Creek to its headwaters on Haw Ridge (Fig. 7). The ^{90}Sr analyses (Table 4) indicate that the activity is discharging from a seep along Racoon Creek tributary stream (RCTS), 29 m upstream from Raccoon Creek. In order to determine whether any additional ^{90}Sr sources are present in this area, the tributary stream was sampled at 5-m intervals near the seep. All the ^{90}Sr is entering the stream within a 10-m interval adjacent to the seep (Fig. 9).

A temporary monitoring station was established on the Raccoon Creek tributary below the ^{90}Sr seep (Fig. 9). An earthen dam was constructed so that stream flow could be monitored with a 40-liter

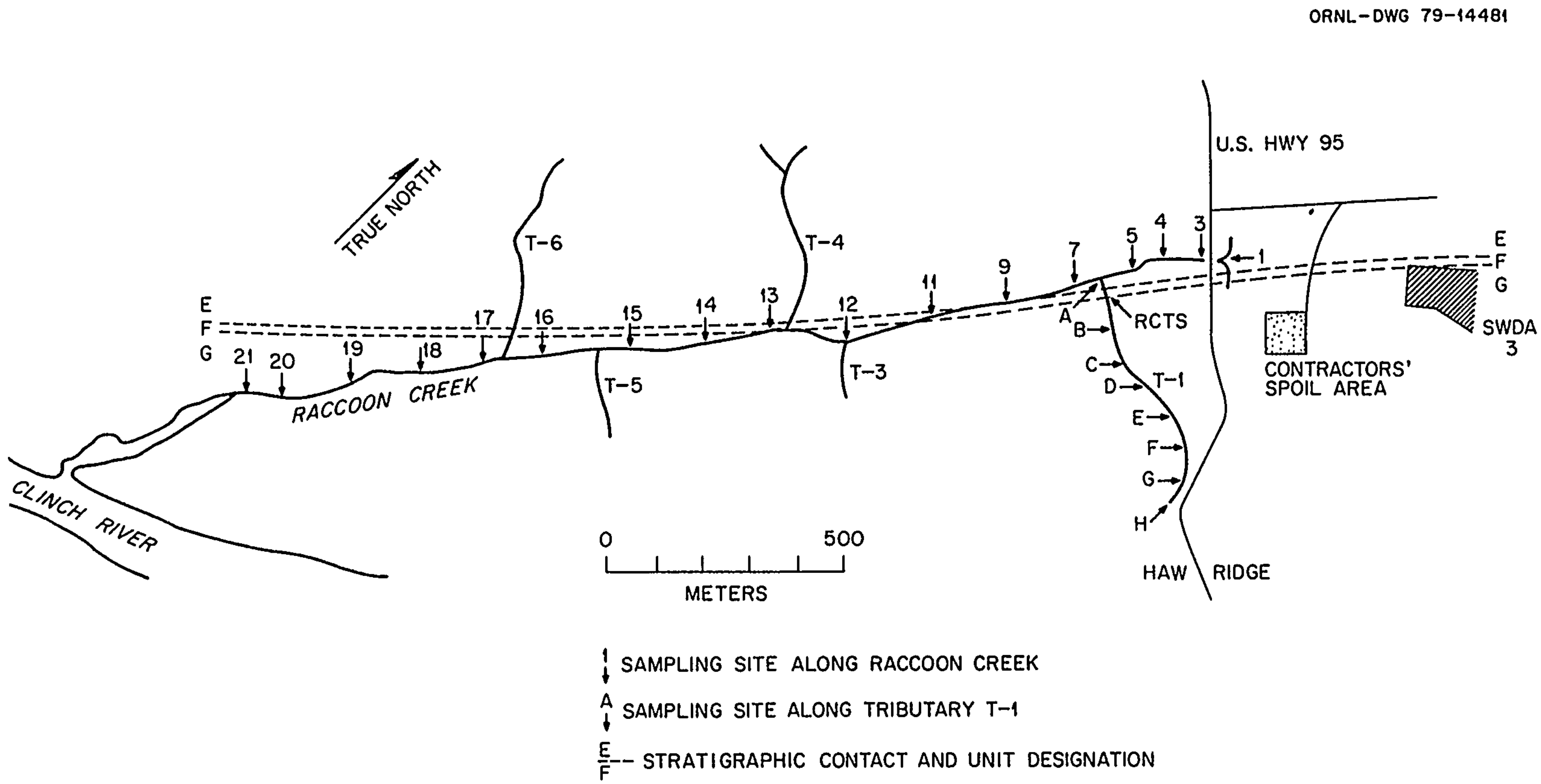

Fig. 7 The Raccoon Creek drainage basin, including surface-water sampling sites and contacts of Chickamauga Limestone bedrock units.

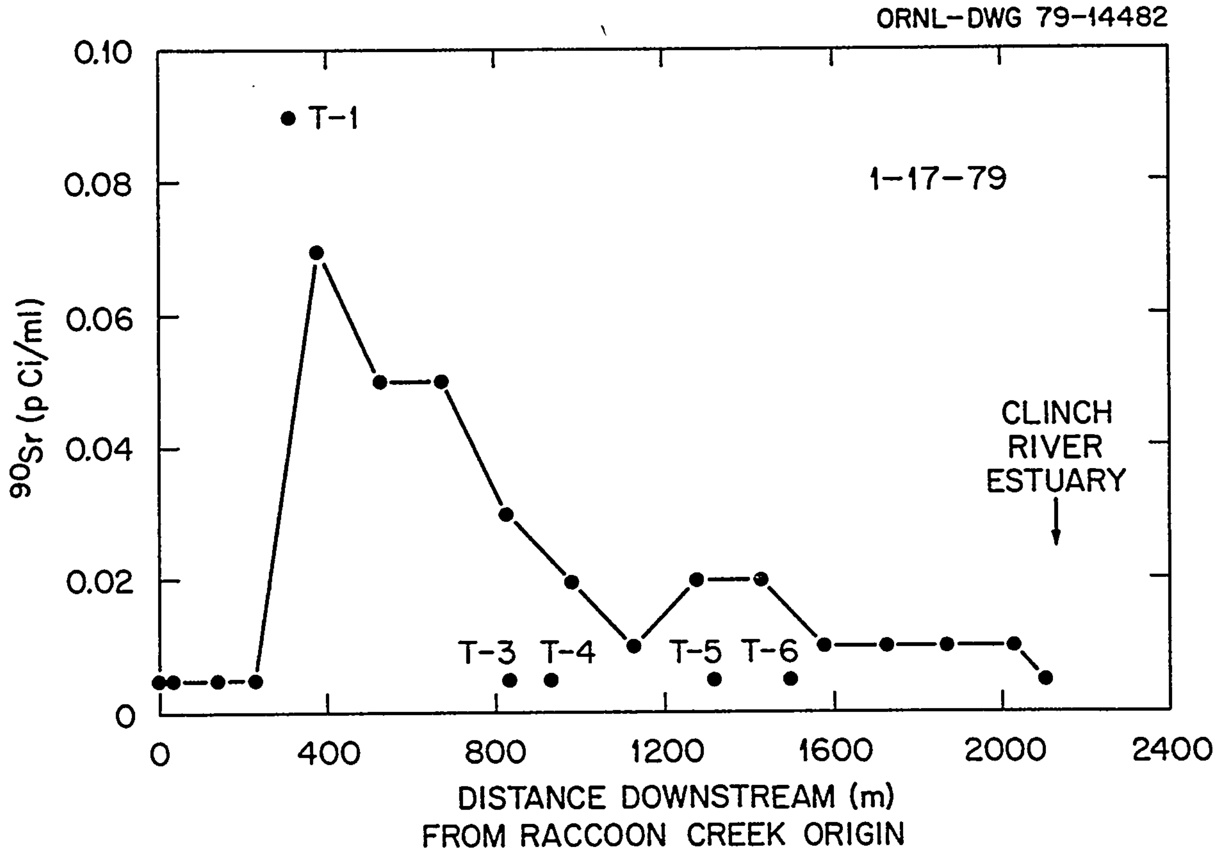

Fig. 8 Longitudinal activity profile of ^{90}Sr in Raccoon Creek on January 17, 1979.

Table 4. Strontium-90 concentrations (pCi/ml) in water samples from the Raccoon Creek tributary stream (RCTS). For sample locations see Fig. 7.

Sample	^{90}Sr	Distance upstream (m)
T-1A	0.03	-
RCTS	0.06	29
T-1B	<0.01	75
T-1C	<0.01	150
T-1D	<0.01	225
T-1E	<0.01	300
T-1F	<0.01	375
T-1G	0.01	450
T-1H	<0.01	468

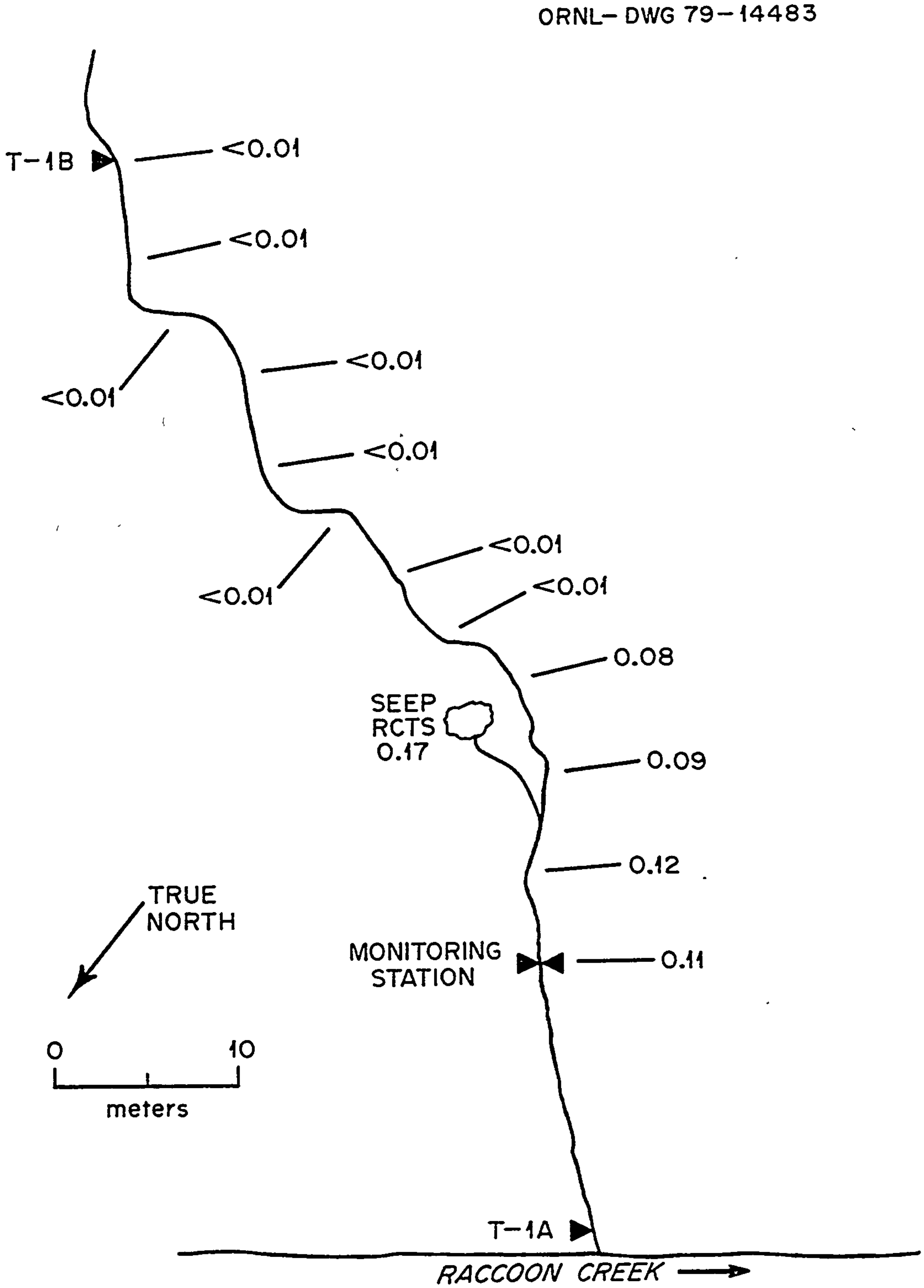

Fig. 9 Sketch map showing ^{90}Sr concentrations (pCi/ml) in the Raccoon Creek tributary stream at 5-m intervals near seep RCTS.

collection vessel and stopwatch. Flow readings and water samples were taken on a daily basis over a three-month period, and the monthly ^{90}Sr discharge (Table 5) was determined in the manner described for the Northwest Tributary. The discharge appears to be fairly constant at about 0.5 mCi per month even though the monthly streamflow varied by as much as a factor of two.

During May 1979, the seep was sampled on a daily basis and composite water samples were prepared for the same time periods covered by daily samples taken at the monitoring station. The ^{90}Sr analyses (Table 6) show that the water discharging from the seep has a relatively constant activity level which is being diminished to varying degrees by tributary streamflow. The lower ^{90}Sr activity of the seep effluent for the last composite sample is probably due to dilution by surface runoff water during a period of high rainfall.

This investigation of the Raccoon Creek watershed demonstrates that ^{90}Sr is being introduced to the surface waters of this drainage basin by ground-water discharge at a single location. The ^{90}Sr discharge, while of very low absolute magnitude, appears to be quite constant. If the radioactive waste in SWDA 3 is the ultimate source of this activity, ^{90}Sr migration over a distance of approximately 640 m is indicated (Fig. 7).

THE CONTRACTORS' SPOIL AREA

The Contractors' Spoil Area (CSA) is located southwest of SWDA 3 near the headwaters of Raccoon Creek (Fig. 7). Earth materials removed during construction activities in the ORNL plant area have been deposited at this site. Because of the possibility that some of these

Table 5. Monthly ^{90}Sr discharge of the Raccoon Creek tributary stream

	3-79	4-79	5-79
^{90}Sr discharge (mCi)	0.513	0.529	0.477
Streamflow (m^3)	7591	14752	12832

Table 6. Strontium-90 concentrations (pCi/ml) in water samples from seep RCTS and from monitoring station on the Raccoon Creek tributary stream

Period	^{90}Sr in seep effluent	^{90}Sr at monitoring station	Streamflow (m^3) at monitoring station
5/1-5/3	0.17	0.09	161
5/4-5/6	0.15	0.02	2962
5/7-5/12	0.17	0.06	488
5/13-5/18	0.18	0.12	232
5/19-5/22	0.16	0.08	718
5/23-5/30	0.09	0.04	6453

materials may be radioactive and may be contributing to the activity found in Raccoon Creek, the spoil area was inspected with a beta-gamma survey meter. Two small areas having radioactivity greater than background level (BKG) were located (Fig. 10); the first (CSA-1) consists of a mixture of soil and gravel whereas the second (CSA-2) is comprised of soil. Representative surface samples were collected from each area, along with a sample from another site nearby in the spoil area where the survey meter indicated a background level of radioactivity. The samples from location CSA-1 were separated into gravel and soil fractions. All samples were analyzed by gamma-ray spectrometry, and the soil samples were analyzed for ^{90}Sr activity (Table 7).

The principal radioactive contaminant in both areas was ^{137}Cs. The ^{90}Sr concentrations in the soil samples were 20 pCi/g or less, with one exception, sample CSA-1-a. On the assumption that these analyses are representative of all the contaminated fill material, calculations of the ^{90}Sr inventory in each area can be made. The depth of the contaminated material in area CSA-1 is uncertain, although the maximum depth of fill material is 6 m (Dvon Brogan, personal communication). If the contamination is uniform and extends to this depth, approximately 200 mCi ^{90}Sr are present in area CSA-1. The fill material in area CSA-2 has the form of a mound on the ground surface. An estimate of about 6 mCi ^{90}Sr has been calculated for this area.

Surface runoff from the Contractors' Spoil Area flows toward the headwaters of Raccoon Creek. In order to investigate the possibility

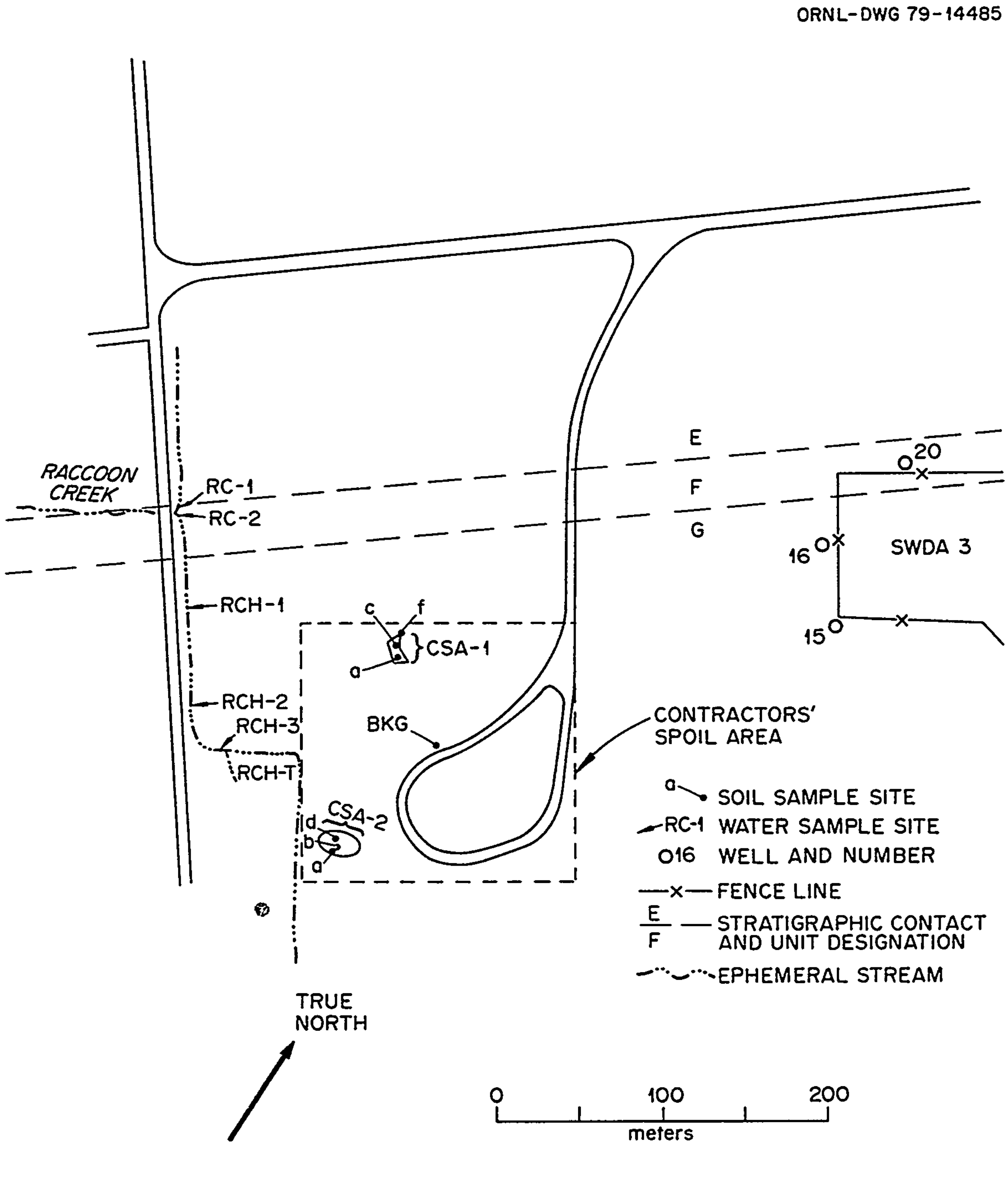

Fig. 10 The Contractors' Spoil Area, showing soil sample locations and surface-water sampling sites.

Table 7. Concentrations of ^{137}Cs, ^{60}Co, and ^{90}Sr (pCi/g) in surface samples from the Contractors' Spoil Area. For sample locations, see Fig. 10.

Sample	^{137}Cs	^{60}Co	^{90}Sr
CSA-1-a			
Soil	1450	$\leq$ 0.20	257.0 (± 27)
Gravel	2680	$\leq$ 0.17	
CSA-1-c			
Soil	959	$\leq$ 0.17	14 (± 8)
Gravel	1080	$\leq$ 0.10	
CSA-1-f			
Soil	9.5	$\leq$ 0.14	17 (± 4)
Gravel	8650	$\leq$ 0.19	
CSA-2-a			
Soil	323	2.3	6.3 (± 4)
CSA-2-b			
Soil	649	4.8	20 (± 11)
CSA-2-d			
Soil	550	3.2	8.6 (± 8)
CSA-BKG			
Soil	3.6	$\leq$ 0.16	1 (± 0.9)

that runoff from the two contaminated areas is contributing ^{90}Sr to Raccoon Creek, surface-water samples were collected from the drainage channels at sites (RCH) shown in Fig. 10 after a storm. The ^{90}Sr analyses (Table 8) indicate detectable but very small activity levels (0.02 pCi/ml or less) in three of the runoff samples, whereas the other three samples had activity levels below the level of detection.

Although surface runoff from the contaminated fill was found to carry only a negligible amount of ^{90}Sr to the Raccoon Creek drainage system, the leaching of ^{90}Sr from the fill and the migration of this radionuclide through ground-water flow represents an additional potential mode of transport to seep RCTS (Fig. 7) and discharge to the Raccoon Creek drainage network. The amount, if any, carried by ground water from this area cannot be estimated at this time because of the absence of wells to the northeast and southwest of the spoil area. It may be noted, however, that, if area CSA-1 were the sole source of ^{90}Sr, its estimated 200-mCi inventory of this radionuclide would be sufficient to maintain the current level of ^{90}Sr discharge of the seep for more than a decade.

DISCUSSION

Observations made during this investigation suggest that ^{90}Sr is migrating from SWDA 3 through ground-water flow over distances of several hundred meters to the northeast and to the southwest to two discrete points of surface discharge (Fig. 11). The trend of a line connecting these two points (N 53 E) passes through SWDA 3 and is parallel to the strike of the bedrock. The possibility that the ^{90}Sr

Table 8. Strontium-90 concentrations (pCi/ml) in surface runoff water samples collected near the Contractors' Spoil Area on February 23, 1979. For sample locations, see Fig. 7.

Sample	^{90}Sr
RC-1	0.01
RC-2	0.02
RCH-1	<0.01
RCH-2	<0.01
RCH-3	0.01
RCH-T	<0.01

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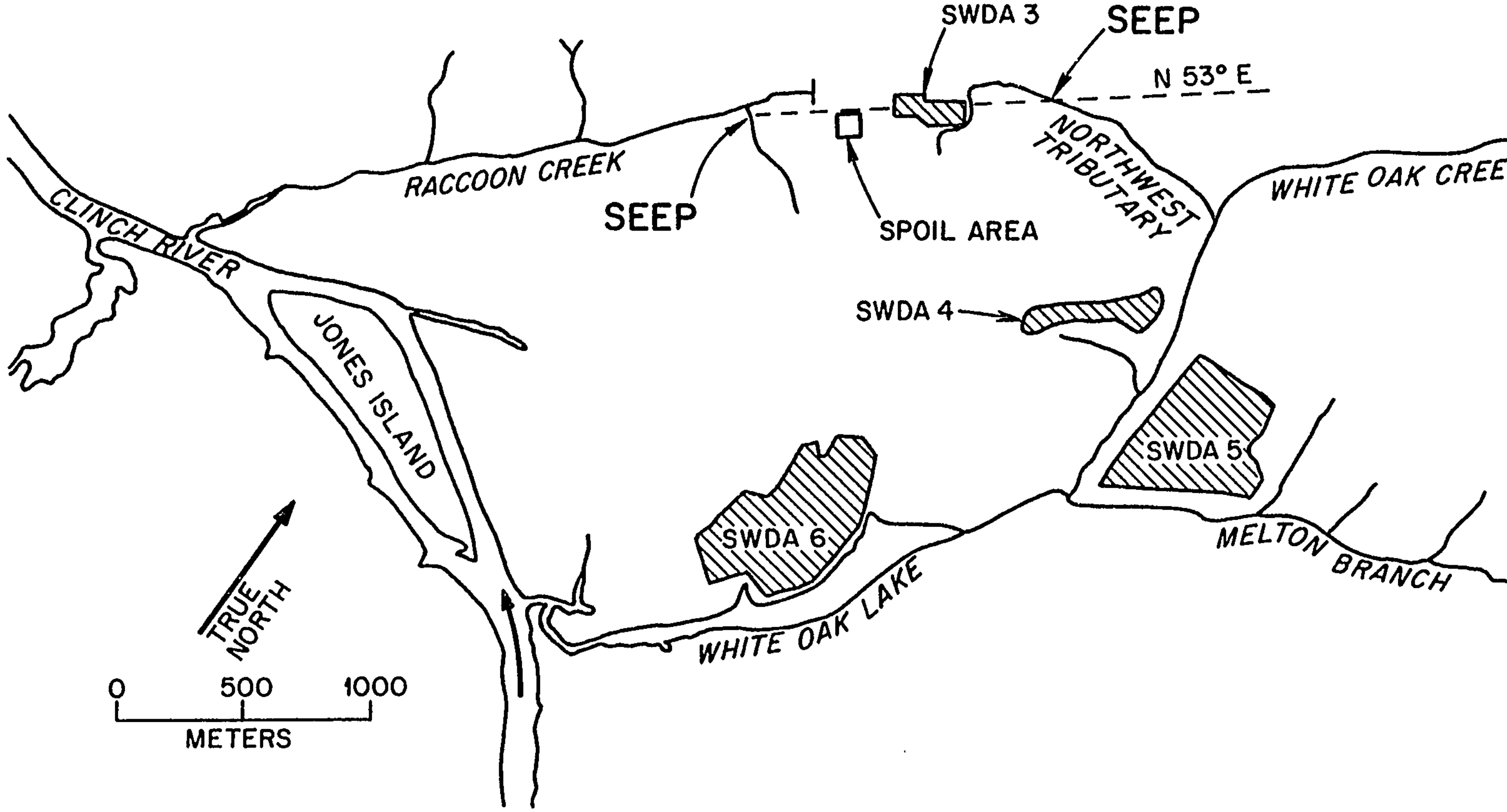

Fig. 11 Drainage systems in the vicinity of SWDA 3, showing the two ^{90}Sr seeps and the trend of a line connecting them.

activity discharging from the seep in the Raccoon Creek watershed is moving underground from the contaminated material in the Contractors' Spoil Area cannot be discounted. The line connecting the two ^{90}Sr seeps also passes near the spoil area (Fig. 11).

With the exception of well 15, analyses of ground water from wells around the perimeter of SWDA 3 indicate that the initial ^{90}Sr movement from the disposal area is in accord with the apparent ground-water gradient. Strontium-90 migration to the points of surface discharge, however, is not. The trend of the line connecting the two seeps suggests that movement of ^{90}Sr to the northeast and to the southwest is occurring by ground-water flow in the bedrock and that the direction of movement is related to bedrock structure. Webster (1976) pointed out that studies of fluid movement in the interbedded shale, siltstone, and limestone of the Conasauga Group (Cambrian age) showed that the principal direction of ground-water flow in the bedrock section of the Conasauga is parallel to strike. He suggested that with increasing depth in the saturated zone there is a change from control of the dominant flow direction by the areal hydraulic gradient to control by the local hydraulic head distribution within the partings, joints, fractures, etc. that are predominantly oriented parallel to strike. It appears plausible that the continuity of openings in the Chickamauga Limestone also may be related to bedrock structure.

All the geologic formations of the Oak Ridge area are of sedimentary origin; they crop out along parallel belts trending northeast-southwest, forming a valley and ridge topography. The direction of strike is essentially constant throughout the area, averaging N 56°E, although slight departures from this average occur from place to place. The formations dip toward the southeast at angles between 30 and 40 degrees.

Stockdale (1951) subdivided the Chickamauga Limestone of Bethel Valley into eight distinguishable and mappable units on the basis of variations in types of rock. These were designated by the letters A to H in ascending order in the stratigraphic column. Three of these units, E, F, and G, form the bedrock surface within and immediately around SWDA 3 (Figs. 3 and 12). Units E and G, which are 116 and 91 m thick, respectively, are both composed of nondescript gray limestones of various types, with thin shaly partings. Unit F, very distinctive and only 7.6 m thick, is a maroon calcareous siltstone and shale. According to Stockdale, this unit probably serves as a stratigraphic trap to prevent free flow and interchange of ground waters between the thick adjoining limestone units.

The nondescript limestones of units E and G are quite compact and devoid of any significant primary porosity (Stockdale 1951). However, secondary openings have developed through dissolution by migrating ground water. On the basis of a study of drill cores from unit G, Stockdale reported solution openings ranging in diameter from a few centimeters to a maximum of about 30 cm. Drilling waters were lost through underground channels in holes 16, 21, and 44 (Fig. 3). A pressure test of a well in the ORNL plant area and examination of cores from several wells indicated that the solution openings in unit G decrease in number and size with increasing depth.

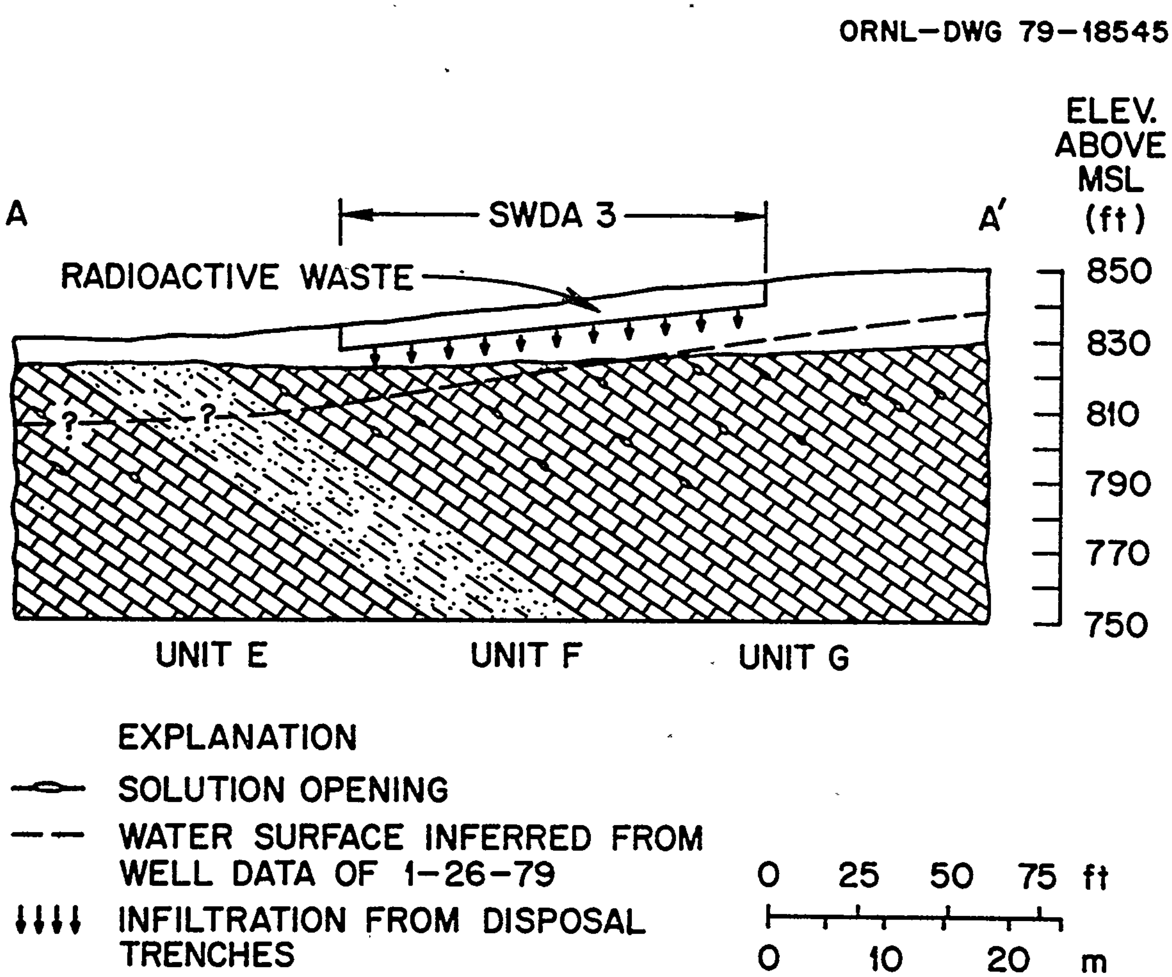

Fig. 12 Schematic cross section through SWDA 3 along line A-A' (Fig. 3) showing significant geologic and hydrologic features.

The presence of secondary openings in the bedrock within and around SWDA 3 does not alone account for ^{90}Sr movement over distances of hundreds of meters. Such migration requires that the openings be interconnected, and the evidence strongly indicates that the apparent interconnection is related to bedrock structure. Thus it appears likely that a bed or horizon within unit G is particularly susceptible to dissolution, so that a drainage connecting the openings has been developed in a direction parallel to bedrock strike. The two ^{90}Sr seeps are located very near the contact between units G and F (Figs. 3 and 7); the interconnection of secondary openings seems to be related to this horizon.

Further information bearing on this possible relationship can be obtained from logs (Stockdale 1951) of core holes 21, 22, and 41 (Fig. 3). These holes are located near the trend line and penetrate both units G and F (Table 2). In hole 21 a solution channel was found at the contact between units G and F, and fluid was lost during the drilling operation. The presence of the solution opening (about 4.7 cm in size) was confirmed by a televiewer log (reflected ultrasonic sound waves recorded photographically) made recently in the hole (Fig. 13). A televiewer log of hole 22 revealed an opening of similar size at the contact between units G and F, although its presence is not indicated in the core-hole log. In hole 41 the driller's log indicates a large cavity within unit F. This also was confirmed by a televiewer log, and a few thousand liters of water were lost in the well during the 50-min logging operation. This rapid loss of water in bedrock further substantiates the existence of a subsurface drainage system.

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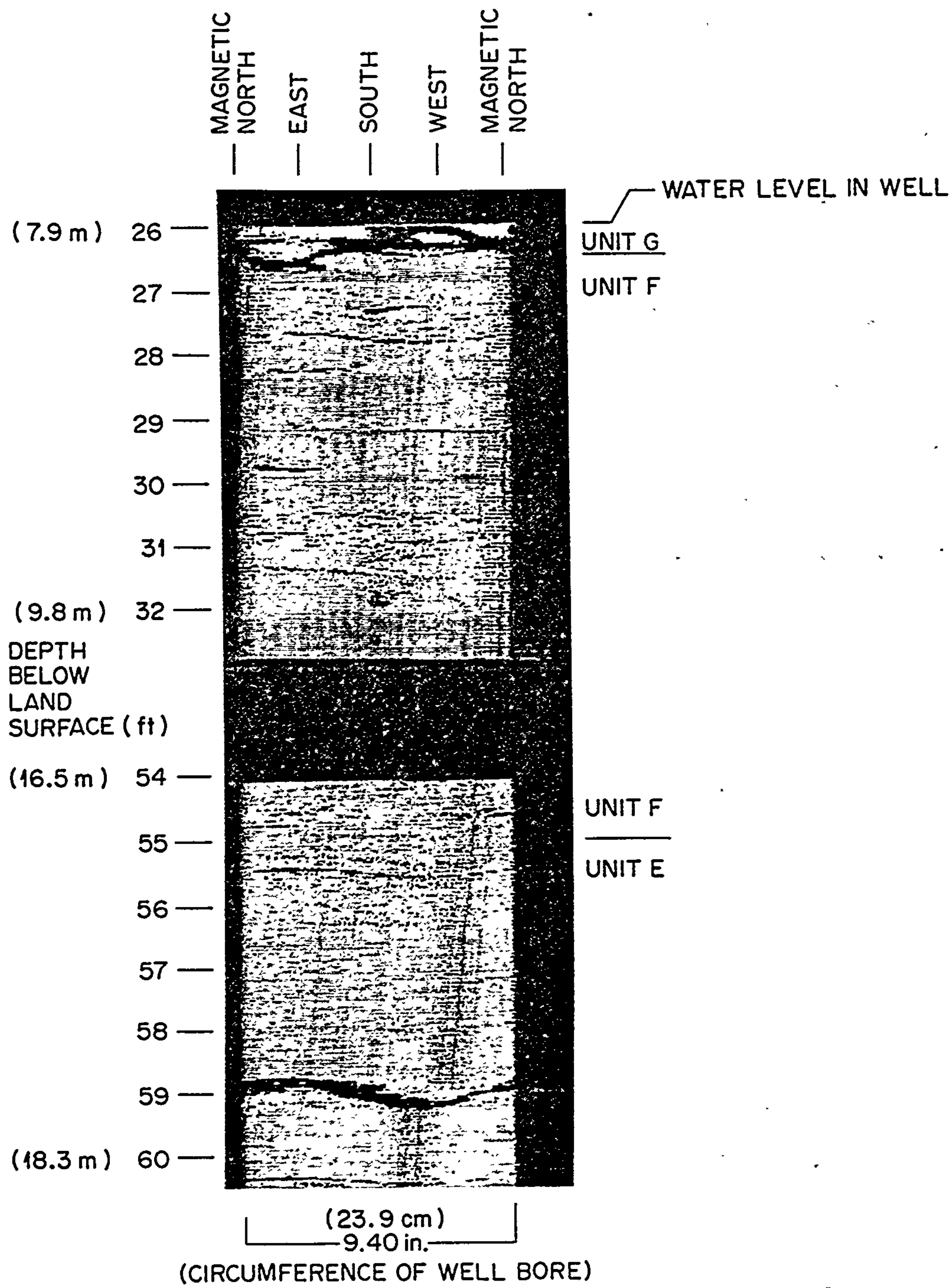

Fig. 13 Portions of televiewer log of well 21, showing major secondary openings in units E and G near contacts with unit F. View is a 360· sweep made from the center of the bore hole.

The movement of ^{90}Sr from SWDA 3 is undoubtedly quite complex, and further studies would be needed to define the migration patterns with precision. However, on the basis of the information at hand, the following tentative interpretation is offered. Strontium-90 leached from the buried waste by ground water moves downward to the saturated zone and migrates generally towards the northwest under the influence of the areal hydraulic gradient until it encounters the contact between bedrock units G and F. To the northeast of the ground-water divide, the radionuclide then moves in a northeasterly direction through a system of solution channels parallel to and in the vicinity of the contact until the channels intersect the land surface to form the Northwest Tributary seep.

Water samples from wells 21 and 22 have comparatively low concentrations of ^{90}Sr (Table 3). The low activity levels may be due to the fact that these wells penetrate bedrock unit E, in addition to units G and F. The activities could be diluted by uncontaminated ground water entering the wells from unit E. Water samples from well 20, which completely penetrates unit F above the zone of saturation and terminates in unit E, have no detectable ^{90}Sr activity, whereas samples from well 41, which ends in unit F, have the highest activity levels detected. The importance of unit F in controlling the underground movement of water and ^{90}Sr is also suggested by the longitudinal activity profiles for the Northwest Tributary, which show that ^{90}Sr does not enter the stream as it flows on the northwest side of the surface expression of this unit (Figs. 3, 4, and 5). The stream is ephemeral in this reach and becomes perennial in the vicinity of the ^{90}Sr seep.

Southwesterly migration of ^{90}Sr to the seep in the Raccoon Creek watershed also appears to be influenced by bedrock unit F, as the seep occurs near the contact between units G and F (Fig. 7). The apparent structurally related control of radionuclide movement is evident whether the ^{90}Sr source is in SWDA 3 or in the Contractors' Spoil Area, or both. Further interpretation is limited at present by the absence of wells in the area. The underground movement of ^{90}Sr in the vicinity of SWDA 3 needs to be studied in more detail through the installation of bedrock wells at strategic locations between the disposal area and the two seeps.

The maximum monthly discharge of ^{90}Sr from SWDA 3 to surface waters of the two drainage basins during the period of sampling was about 11.6 mCi; this represents a very minor portion of the total ^{90}Sr monthly release to the environment from the ORNL radioactive waste disposal areas. The implications of the extensive migration of ^{90}Sr through bedrock are probably of much greater consequence than the actual radionuclide discharge. There are limestone units of significant thicknesses within the Conasauga Group in Melton Valley where much larger quantities of radioactive waste are buried. These units may contain secondary openings providing pathways for underground radionuclide migration from the waste disposal areas and possibly from the White Oak Creek drainage system. The Knox Dolomite (Cambrian and Ordovician age), exposed along Chestnut Ridge northwest of Bethel Valley, contains solution openings of substantially larger size than those found in the Chickamauga Limestone. The potential for radionuclide migration through these openings should be considered in any evaluation of the Knox for the development of waste disposal sites.

SUMMARY AND CONCLUSIONS

The results of this investigation indicate that ^{90}Sr is the only radionuclide being discharged from SWDA 3 in solution to the surface waters of the White Oak Creek drainage basin. This ^{90}Sr discharge, measured in the Northwest Tributary near its confluence with White Oak Creek, amounts to about 6 or 7 mCi per month on the average. The radionuclide is apparently moving from buried waste in SWDA 3 via ground-water flow, entering the Northwest Tributary within a 30-m reach located about 350 m from the disposal area. Only negligible amounts of the ^{90}Sr in the stream can be attributed to leaching of the contaminated equipment and other items that have been stored on the surface of SWDA 3.

Strontium-90 activity has also been detected in waters of the Raccoon Creek drainage system. The radionuclide is discharging to surface water from a seep located adjacent to a Raccoon Creek tributary stream. The ^{90}Sr discharge is persistent at about 0.5 mCi per month. If the source of this activity is in SWDA 3, as suggested by the apparent presence of a ground-water divide beneath the southwestern end of the disposal area, the ^{90}Sr has migrated underground over a distance of about 640 m. Two small areas of radioactively contaminated fill material have been identified in the Contractors' Spoil Area, located approximately 250 m southwest of SWDA 3. The ^{90}Sr discharging from the seep could also be migrating underground from this source.

The movement of ^{90}Sr via ground-water flow to the northeast and to the southwest of SWDA 3 appears to be related to bedrock structure, as the trend of a line connecting the two points of surface discharge is parallel to bedrock strike. Within the Chickamauga Limestone of Bethel Valley, bedrock unit F, a calcareous siltstone and shale, may be important in controlling the underground movement of water and ^{90}Sr. The two seeps are located very near the contact between unit F and unit G, which is composed of shaly limestones. Information from core-hole logs and televiewer logs suggests that ^{90}Sr in ground water may be moving through solution channels developed parallel to and in the vicinity of this contact.

Although the present ^{90}Sr discharge from SWDA 3 to surface waters is very small when compared to discharge from other sources, the movement of this radionuclide from the disposal area should be studied further through continued surface-water monitoring in both drainage basins and through the installation of additional wells. A more thorough understanding of the underground ^{90}Sr migration patterns around SWDA 3 is needed because of the potential for development of additional solution openings resulting in flow to other points of discharge, and because of the possibility of radionuclide movement at depth in Melton Valley where SWDAs 4, 5, and 6 are located. It is also important to increase our understanding of radionuclide transport in this type of hydrogeologic environment in general.

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APPENDIX A

STRONTIUM-90 ANALYSES OF SURFACE-WATER SAMPLES COLLECTED FROM THE NORTHWEST TRIBUTARY AND RACCOON CREEK DRAINAGE BASINS

Table A-1. Strontium-90 analyses (pCi/ml) of surface-water samples collected from the Northwest Tributary (NWT) and its tributary streams (T) in June 1978. For sample locations[a], see Fig. 3.

Sample	June 6, 1978	June 9, 1978
NWT-1	0.05	0.05
NWT-2	0.05	0.06
NWT-3	-	-
NWT-4	0.35	0.09
NWT-5	0.40	0.10
NWT-6	2.93	0.12
NWT-7	0.03	0.09
NWT-7A	0.03	-
NWT-8	0.03	0.03
NWT-8A	0.03	-
NWT-8B	0.05	-
NWT-9	-	0.04
NWT-9-1	0.01	-
NWT-9A	0.07	0.02
NWT-9A-1	0.01	-
NWT-9B	0.01	< 0.01
T-1	0.02	< 0.01
T-2	< 0.01	< 0.01
T-3	< 0.01	< 0.01
T-4	-	0.03
T-5	-	0.01
T-6	-	0.02
T-8	< 0.01	0.02
T-9	< 0.01	< 0.01
T-10	-	0.05
T-12	-	< 0.01
T-14	-	< 0.01

[a]The locations of most sampling sites designated with the suffix A, B, or 1 are not shown on Fig. 3. These samples were taken from pools of water in the streambed at points upstream from the 150-m site indicated by the sample number. For example, sample NWT-7A was collected at a point between sites NWT-7 and NWT-8; sample NWT-9-1 was taken at a point between sites NWT-9 and NWT-9A.

Table A-2. Strontium-90 analyses (pCi/ml) of surface-water samples collected from the Northwest Tributary (NWT) and its tributary streams (T) in January 1979. For sample locations, see Fig. 3 and footnote following Table A-1.

Sample	January 5, 1979	January 18, 1979
NWT-1	0.06	0.05
NWT-2	0.09	0.10
NWT-3	0.09	0.11
NWT-4	0.12	0.20
NWT-5	0.10	0.19
NWT-5A	0.29	1.13
NWT-5B	0.33	1.13
NWT-5C	0.33	1.13
NWT-5D	0.36	1.08
NWT-6	0.34	1.04
NWT-6A	0.37	1.04
NWT-6B	0.35	1.08
NWT-6C	<0.01	0.01
NWT-6D	<0.01	0.01
NWT-7	<0.01	0.01
NWT-7A	<0.01	0.02
NWT-7B	0.01	0.02
NWT-7C	0.02	0.01
NWT-7D	<0.01	0.01
NWT-8	<0.01	0.01
NWT-9	0.03	0.03
NWT-9A	<0.01	<0.01
NWT-9B	<0.01	0.01
T-1	0.01	0.01
T-2	<0.01	<0.01
T-9	<0.01	<0.01
T-10	<0.01	<0.01
T-12	<0.01	0.05
T-14	<0.01	0.05

Table A-3. Strontium-90 analyses (pCi/ml) of surface-water samples collected from Raccoon Creek (RC) and its tributary streams (T) on January 17, 1979. For sample locations, see Fig. 7.

Sample	^{90}Sr
RC-1	<0.01
RC-3	<0.01
RC-4	<0.01
RC-5	<0.01
RC-7	0.07
RC-9	0.05
RC-11	0.05
RC-12	0.03
RC-13	0.02
RC-14	0.01
RC-15	0.02
RC-16	0.02
RC-17	0.01
RC-18	0.01
RC-19	0.01
RC-20	0.01
RC-21	<0.01
T-1	0.09
T-3	<0.01
T-4	<0.01
T-5	<0.01
T-6	<0.01

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